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The Baker's Dozen: Key Nations Can and Should Act Together to Prevent Further Dangerous Climate Change[1]

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Abstract: Most international responses to climate change assume we need a 'global' solution. Game theory and political science both support limiting the negotiating parties to enable a more rapid and aggressive response. Given that 90 percent of emissions come from 12 percent of nations, we argue if a 'Baker's Dozen' of nations bands together, they can make great strides in combating climate change. With aggressive measures, their action would be sufficient to greatly reduce the likelihood of additional dangerous climate change, defined as widespread and irreversible change. We give three reasons why these nations should act: ability to act; responsibility to act; self-interest in acting.

Introduction

The projected impact of severe climate change, the urgency of cutting greenhouse gas emissions, and the current political environment offer a unique moment for reconsidering policy options for curbing global climate change. Most international responses to climate change assume we need a 'global' solution, in which most if not all of the world's nations participate in an emission reduction agreement. But the majority of the world's emissions derive from a handful of nations, so we may be able to achieve sufficient reductions by involving fewer nations. Limiting the negotiating parties may enable a more rapid and aggressive response. This paper asks the question: can and should a sub-group of nations act together to avoid further dangerous climate change? We conclude yes on both counts. This approach is not new – we base it on lessons from political science and game theory. Our paper seeks to establish that this approach also has scientific and moral justification. We first argue that if a sub-group of key nations bands together, they can make great strides in combating climate change; with aggressive measures, their action would be sufficient to greatly reduce the likelihood of additional dangerous climate change as we define it. Our second major argument addresses why these key nations should take immediate action; we give three reasons. First, the subgroup is able to significantly decrease the likelihood of dangerous climate changes and the participation of certain nations is critical. Second, all key nations bear responsibility for acting because of their historical or projected future emissions. Third, it is in the interest of these nations to act to mitigate dangerous climate change.

> Ignoring climate change will be the most costly of all possible choices, for us and our children.
> / Peter Ewins /

Lessons from game theory and political science

Insights from game theory and political science make the case that a core group of nations may be more effective in reaching quick and ambitious agreements than working to achieve a global consensus. The major insight from these literatures is that any agreement has to be in the best interest of each of the parties. If a country feels like the cost of accession to the agreement outweigh the associated benefits (or benefits from defection outweigh the costs), then the agreement will not form or endure, because countries will defect, cheat, or refuse to take part. The following four overlapping lessons derive from game theory and political science literatures and can be used to analyse international agreements.[5]

(1) Game theory shows that a large group negotiation will lead to consensus matching the aspiration of the least ambitious party. This is supported by political science: as the number of interests in a negotiation increase, the harder it is to find a combination of measures that will make each nation better off. If we need to meet ambitious targets, we would do better to limit the number of negotiating parties.

(2) When many parties are involved in an agreement, there is little cost to defection and little benefit of accession for any individual actor. This means all nations will have a strong incentive to free ride, and their defection (or accession) will have little effect on other parties. Any agreement will therefore never be in equilibrium, parties will defect, and the environmental effect will be minimal.

(3) A more likely long-term, self-enforcing, and adaptable global solution will arise when multiple, variable-sized coalitions each determine their own appropriate aspirations and national actions to meet the set goals. The likelihood of accession and self-enforcement of national actions will be much higher under this model.[6] The more inflexible the policy targets, the less likely a multiparty solution will form or endure because nations will not be able to implement national measures aligned with their interests and, moreover, their national institutional capacities.

(4) Some nations will need to pay other nations to keep them as parties. Given the political debate of global climate change, no agreement will include lesser-developed nations unless more-developed nations (who, not coincidentally, have higher historical emissions) agree to pay them. Game theory, too, establishes the importance of side payments from rich nations to keep poorer nations as parties to agreements.[7]

These extensive literatures provide one very important lesson: a global agreement on climate change is very unlikely, and what will result will be inadequate and unstable. We are more likely to see coalitions and parallel agreements where some countries do more and all parties take a bottom-up approach reflecting their national incentives and institutional capabilities.

Empirical evidence also speaks to the utility of side agreements in international environmental policy. The decade between the establishment of the climate change framework convention and the ratification of the implementing protocol, and the US's refusal to ratify the protocol, are evidence of the difficulty of coordinating diverse national interests.[8] The Montreal Protocol, one of the most successful international environmental agreements,[9] started with just 28 nations. Recent policy discussions, for example at the G20 or the L20, have focused on developing an international climate change policy based on initial agreements by a select group of nations. However these discussions have occurred under the shadow of on-going international climate negotiations and there

is significant evidence that agreeing to side-deals prior to wider negotiations could lead to worse environmental outcomes when these deals are not contingent on later action by other negotiating parties.[10] We cannot say how these discussions would have ended had there been no concurrent global negotiation process.[11]

Urgency of and thresholds for required action

Dangerous climate change is a normative concept describing a situation where the impacts of climate change have exceeded a level society has deemed to be acceptable; it is a value judgment informed by our scientific understanding of projected climate change impacts. No specific definition of 'dangerous anthropogenic interference' was delineated in the United Nations Framework Convention on Climate Change, in part because what constitutes 'dangerous' can differ based on differing worldviews, values, geographic location, or abilities to adapt. We assess what is dangerous through the lens of human welfare, which we consider to be normatively valuable and worth protecting, now and into the future. Since human welfare relies on services provided by the earth, the loss of essential services without the possibility of replacement, restoration, or substitution constitutes a dangerous impact.

Given the goal of avoiding further dangerous climate change, scholars have worked on defining the interrelated physical metrics of an acceptable temperature rise, determining what the associated atmospheric stabilisation level would be, and then estimating what annual emissions pathway or cumulative emissions budget would enable us to keep to that stabilisation target. These studies converge on some targets for allowable temperature change, stabilisation concentration, and emissions levels. We note that these targets are still uncertain and fraught with value judgments, especially with regard to the embedded assumptions about acceptable levels of risk. To produce a policy-relevant cumulative emissions budget, we specify (a) an acceptable temperature rise, and (b) a long-term atmospheric carbon dioxide stabilisation level and the short-term overshoot of the stabilisation target.

We set our target stabilisation temperature at 1 degree Celsius above 2000 levels. Our target translates to ~1.6 degrees above pre-industrial temperatures, slightly below the 2-degree EU policy target and roughly equivalent to the 1.5-degree limit proposed by the Alliance of Small Island States.[12] We follow other studies drawing on the IPCC's "Reasons for Concern" as a way to define what temperature change could be considered "dangerous" if sustained over the long-term[13] They represent the developers' best approximation regarding the magnitude of risk in each category we can expect at different temperature levels. For our purposes, we consider running a "severe risk" within these Reasons for Concern as an appropriate threshold for dangerous because, as we will show, this would trigger impacts that threaten the irreversible loss of services important to many people's welfare.

A recent update of the temperature change that would induce severe risk in each Reason for Concern gives a range of 1 – 2.5 degrees warming above 2000.[14] Within that range, where we should set the threshold depends on value judgments about the relative importance of each Reason for Concern. Setting a threshold at 1 degree above 2000 would avoid running a severe risk for all. Even at this level, we will face a litany of impacts and a greater than 1-degree rise could result in far worse consequences due to non-linearities in the climate system and the surprises they could bring.

With a 1-degree above 2000 rise in global average temperature, we will likely experience significant, widespread impacts and associated risks to unique and threatened ecosystems, including more frequent and extensive coral bleaching and increased vulnerability of Arctic and small island communities. We will also experience increased intensities in extreme weather events, such as cyclones, heat waves, droughts, and floods, which will in turn cause more deaths, injuries, and damage to property. People living in poor, low-lying, low-latitude areas will run the highest risk, but people in rich nations are not immune to vulnerabilities (as evidenced, for example, by deaths from the heat waves in Europe in 2003).

Perhaps most salient to our argument, with a 1-degree rise, we will run a moderately significant risk of large-scale discontinuities in the climate system, including such impacts as partial or full deglaciation of the Greenland and West Antarctic Ice Sheets. If this melting were to occur, sea levels could rise many meters and life-sustaining ocean currents could be disrupted.[15] A large portion of the earth's freshwater has, for many, many years been trapped in these ice sheets.[16] These reservoirs of ice serve multiple physical functions including the storage of water and reflection of sunlight. A number of large-scale impacts would result from the loss of these ice sheets. Their complete melting could cause a sea level rise of up to 12 meters, while partial melting, predicted to occur over centuries, could cause a sea level rise of up to 6 meters. This rise would permanently flood many coastal and low-lying areas, including New Orleans, the Netherlands, Bangladesh, and most low-lying, small island nations. This would affect any nation with a coast, which depends upon coastal infrastructure (such as ports in nearby nations or trading partners), or which cannot adapt to rising sea levels. Secondly, the influx of freshwater could change global ocean circulation. Climate change-induced melting of ice will affect ocean currents by causing an influx of less dense freshwater. Similarly, stratification of the ocean's water will be fortified by warming of surface water, preventing mixing. The ocean is one of the planet's most important carbon sinks. Ocean circulation regulates the contact of deep ocean water with the atmosphere, governing carbon uptake by the ocean. An alteration of this carbon exchange will decrease the amount of carbon dioxide taken out of the atmosphere by the ocean. The third widespread impact caused by the partial loss of the ice sheets is loss of snow/ice cover. Loss of snow/ice cover causes a positive feedback by reducing the Earth's reflectivity, therefore causing more of the sun's heat to be absorbed. This feedback will accelerate climate change.

> The issue of climate change is one that we ignore at our own peril.
> / Barack Obama /

Distressingly, warming estimated as 'in the pipeline' is already slightly over this 1-degree target.[17] In other words, this amount of warming will likely occur even if we could freeze atmospheric concentration of carbon dioxide at today's level of 385 ppm CO_2 because of inertia in the climate system (compare with pre-industrial levels of about 280 ppm). Based on Solomon et al, Meinshausen el al. and Hansen et al., we set our long-term stabilisation target at no more than current concentrations.[18]

The immense inertias in both the climate and social systems require us to exceed the long-term target by a certain amount for a certain amount of time while policy measures take effect and past emissions embedded in the climate system run their

course.[19] The lower and shorter the overshoot, the smaller the probability of widespread, irreversible change.[20] In our scenario, the overshoot peaks at ~427 ppm CO_2 in 2050, and declines thereafter, achieving stabilisation back at 385 ppm CO_2 around 2150.[21]

Given the limits we have determined about temperatures and the associated stabilisation overshoot scenario, we are now prepared to set an appropriate level of total global emissions between the years 2000 – 2050; a value we will refer to as *cumulative emissions*. Numerous studies have estimated the cumulative emissions we can generate over the remainder of the first half of this century. To meet the stabilisation level we have chosen, the cumulative global emissions budget for carbon dioxide emissions from fossil fuel consumption over the period 2000 – 2050 is around 290 gigatons carbon (GtC)[22]

Our proposal: A side agreement

Our proposal is for a sub-group of nations to make a side agreement and thereby greatly decrease the likelihood of further dangerous climate change. This section makes the scientific case for our approach. As relatively few nations are responsible for the vast majority of global emissions, international agreements to reduce those emissions significantly do not require the involvement of all nations. As Figure 1 illustrates, we gain a significant amount of leverage from surprisingly few nations, with 90 percent of emissions coming from 12 percent of nations.[23] The figure shows the cumulative emissions of countries ranked by their national annual emissions in 2004.

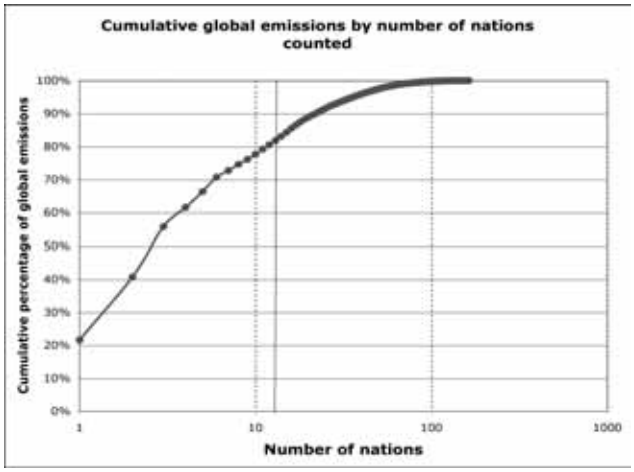

Figure 1: Cumulative global emissions by number of nations counted. Vertical line delineates the top thirteen global emitters, a group we refer to as the 'Baker's Dozen'. Note that the x-axis is presented on a log scale.

Model

We have two criteria for an eventual side agreement. First, it must be able to get global emissions within limits to meet our cumulative emissions budget. Second, the called-for measures must be within reasonable bounds of technical feasibility. For the reasons explained above, we limit the number of actors in the agreement. For our model, we selected the minimum number of nations required by ranking countries by their current annual emissions; we discuss this a bit later.

A number of possible scenarios of national-level action emerge to cut emissions of carbon dioxide from fossil fuel consumption. The question is which option can keep us below our defined 290 GtC cap. We model scenarios varying five parameters: (i) countries involved, (ii) required annual emissions reductions, (iii) necessary annual sequestration, (iv) the year in which emissions peak, and (v) the year in which sequestration begins. We set a number of conditions: (a) emissions reductions cannot exceed 5 percent a year, (b) sequestration potential cannot exceed n*5 percent of 2000 emissions levels, where n is the number of years after sequestration started (so the first year, a nation sequesters the equivalent of 5 percent of its 2000 emissions, the second year 10 percent, the third year 15 percent, and so on until 2050), and (c) wealthier nations have to start reducing emissions and sequestering earlier than developing nations. While the bounds for emissions and sequestration are aggressive, they fall within the range deemed reasonable by climate scholars and industry analysts.[24]

These scenarios are based on a simple model of national carbon dioxide emissions from fossil fuel consumption, cement manufacturing, and gas flaring using data on past emissions by countries.[25] We separated countries into two development categories where most developed are countries considered high income per the World Development Indicators, and least developed are all others.[26] We grouped the 27 European Union countries and considered them as one entity; and we removed Iran from the sub-group. We calculated the emissions growth rate over the period 2002–2004 to extrapolate emissions in 2005–2009. Our model disaggregates required emissions cuts by country, given a future date after which emissions must decline (called the peak year) and a future date at which sequestration must begin (called the sequestration year). Emissions decline at a constant annual rate after the peak year until the nation's emissions reach zero. Every year after the sequestration year, a nation's sequestration ca- pacity increases a set percentage of its year 2000 emissions. We assume emissions from nations not within the Baker's Dozen would continue to grow at the global average historical rate of over 3 percent a year.[27]

With these assumptions, we find a group of only thirteen nations is necessary to stay below the cap and keep reductions and sequestration within reasonable bounds (represented by the vertical line in Figure 1). While these nations must abide by strictures, emissions from the rest of the world can continue growing at historical rates. This group, which we refer to as the Baker's Dozen – the US, the EU-27, China, Japan, Russia, India, Canada, South Korea, South Africa, Mexico, Indonesia, Australia, and Brazil – must agree to aggressive annual reductions (5 percent) starting in 2012 for developed nations and 2015 for developing nations. As shown in Table 1, to meet the cumulative emissions cap of 290 GtC, these reductions need to be coupled with aggressive sequestration (5 percent of 2000 level emissions, growing at an additional 5 percent each year thereafter) starting in 2015 for developed nations and 2030 for developing nations. Reducing emissions could be achieved by, for instance, improving energy efficiency or switching to low-carbon fuel sources. Carbon sequestration involves removing carbon already emitted from the atmosphere in order to achieve a negative rate of emission growth; examples include carbon capture and storage and reforestation.

In this scenario, the thirteen nations must sequester 132 Gt C by 2050; which seems to be within the bounds of estimated global potential.[28] By 2050, these nations would be sequestering 8 Gt C per year. Studies seem optimistic that research and development will reduce costs of carbon sequestration technologies and these, combined with efficiency, better agricultural and forestry practices, and fuel switches, can bring us within the required bounds,[29] although others are more skeptical.[30]

Annual Emissions Reductions	Sequestration Capacity Annual Increase (as percentage of 2000 emissions, increases linearly on annual basis) 0%	0.50%	1%	2%	5%	10%
0%	617	603	590	564	484	351
1%	557	544	531	504	425	292
3%	491	477	464	438	358	225
5%	418	405	392	365	285	153
10%	347	333	320	294	214	81
20%	299	286	273	246	167	34

Table 1: Cumulative global emissions by 2050 with thirteen minimal nations in agreement. Values in white fall below the cumulative emissions cap of 290 Gt C required to avoid further dangerous climate change. The grey box indicates sequestration and emission reductions within reasonable bounds of technical feasibility.

Why key nations should (and must) act to prevent DCC

Having established that key nations can act to make significant gains in averting dangerous climate change, we identify three separate reasons why they should act.

Preventing further dangerous climate change requires the action of essential nations

The nations in the Baker's Dozen have it in their power to effectively prevent further dangerous changes. Significant action has to be taken now if we are to effectively combat dangerous climate change. Pumping ever more greenhouse gases into the atmosphere locks in further warming and all its associated impacts. The current growth in global emissions is increasing the likelihood of irreversible, dangerous changes and decreasing the likelihood we will be able to adapt. We believe the physical and moral necessity of preventing the worst outcomes of dangerous climate change is so urgent it should trump other considerations normally embedded in climate agreements, if (and only if) those considerations are stumbling blocks for immediate action. Arguments from other areas of policy making substantiate the justification for prioritising action when a crisis threatens.[31]

The Baker's Dozen are among the most able to act to prevent dangerous climate change. The rich, highest-emitting nations have money to invest, e.g., in the research and development of clean technologies, and they have consumption habits that can be altered to reduce per capita emissions, e.g., eating less meat and instigating energy efficiency standards; while the highest emitting developing nations have the most potential for changing their development paths to less carbon-intensive ones, e.g., by adopting carbon-free energy technologies developed in the richer nations or adopting efficiency codes for buildings.

Some nations within the Baker's Dozen are essential parties because without them, no agreement will prevent dangerous climate change. Because the currency we need to reduce is cumulative emissions from 2000-2050, the most important actors are those who are – or who will be – the largest emitters over that period. By paring down the subgroup to a minimal thirteen, our model shows we cannot avoid further dangerous climate change without significant action by all these players. If we expand the number of nations slightly, however, for example adding in the next 7 top emitters (Iran, Saudi Arabia, Ukraine, Taiwan, Thailand, Turkey, and Kazakhstan), the only nations with the power to cause a failure if one were to defect are China, the US, and the EU-27. China is always an essential player; without action from China, the rest of the world will have a difficult time staying under the cap even if they enact significant cuts and sequestration efforts.

The thirteen nations included in our model are a rough approximation of what a subgroup might look like. We find thirteen parties are minimally necessary to achieve the cap and meet our conditions regarding emissions cuts and sequestration. We are interested in establishing the minimal number of parties because a smaller group has advantages, as we have already discussed. The exact membership of a sub-group is not prescribed by our approach – we could come up with a different list and defend it both empirically and normatively, for example by substituting one country for one or more with similar emissions. Nonetheless, we believe the Baker's Dozen is a sub-group with bite: with just thirteen nations, we capture 83 percent of global emissions; to get just 9 percent more would require doubling the number of negotiating parties. Further, these nations are particularly able to act and, as we discuss next, bear disproportionate responsibility.

Responsibility supports necessity of action by key nations

We believe responsibility for preventing the crossing of the dangerous threshold lies with those most responsible for contributing to the problem and those who will contribute to the problem if they do not significantly rein in their emissions. The wealthier nations bear the greatest historical responsibility for increasing the atmospheric concentrations of greenhouse gases, which is why mitigating dangerous climate change is such a pressing issue in the first place. Moreover, their greater wealth is due in large part to these emissions. They therefore have more responsibility for taking action. The less developed nations in the Baker's Dozen accrue responsibility to act as well because of their projected future emissions. They are projected to have significant emissions growth if they develop on a business-as-usual, carbon-intensive pathway. As a result of their economic development, these nations' emissions are growing at rates far higher than developed nations. Indeed, in 2008, China surpassed the US in terms of absolute emissions (though per capita is still far lower).

> Given the nature and magnitude of the challenge, national action alone is insufficient. No nation can address this challenge on its own. No region can insulate itself from these climate changes. That is why we need to confront climate change within a global framework.
> / Ban-Ki Moon /

Concerns about equity go hand-in-hand with historical responsibility. Negotiations are often bogged down by concerns that developing nations will be condemned to lower levels of economic development if they are required to curb their emissions. Equity and fairness considerations, it seems, suggest less developed nations should have the same rights and abilities to develop that wealthier countries had, especially since their emissions have to be reduced because of the emissions (and associated development) of richer nations. We have shown, however, if key developing nations continue on emissions-intensive development paths, dangerous climate change will ensue; their involvement in an agreement is crucial.

The seeming contradiction between moral and pragmatic arguments regarding developing nations' emissions pathways can at least in part be reconciled by an agreement among the Baker's Dozen with differential responsibilities for less and more developed

parties. Our proposal includes differential responsibilities for action based on a nation's level of development and corresponding contributions to climate change. For example, our approach allows developing nations to have more time to begin cuts; developed nations will make side-payments to less developed nations to keep them as parties to the agreement; and the parties involved can negotiate future reevaluations to assess if developing countries, despite legitimate efforts to cut emissions, are falling behind economically, in which case developed nations should have to cut more.

It is in the self-interest of key nations to act

To protect their national interests, the nations in the Baker's Dozen should act to prevent dangerous climate change. As we have presented above, dangerous climate change will cause widespread negative impacts around the world. The nations in the Baker's Dozen will only bear a fraction of the global damages from climate change, but as increasing evidence suggests the costs could be enormous and, if severe climate change occurs, it could be socially destabilising on a global scale.[32] While the key nations will likely not suffer the worst impacts of dangerous climate change relative to all nations when measured as percentage of GDP, percentage of population affected, or severity of impacts, they will nonetheless experience significant negative impacts. Dangerous climate change is a global threat and the extent of the national-level projected impacts can be interpreted as threats to national security. As such it is in every nation's self-interest to act to prevent it. The self-interest argument is also one about moral duties. These countries have a duty to protect their own citizens.

It may seem unfair to focus on just a few nations – whether the Baker's Dozen or another sub-group – when all nations arguably have a duty to act to prevent further dangerous climate change. We believe that the duty to act also involves entering into the most promising negotiations with other countries seeking to fulfill their duties. This implies that nations may be morally obligated to enter into side agreements if these are the most promising way to advance serious climate change solutions. Further, the nature of the problem we are facing – its severity and its urgency – means that we have little time to worry about only 'doing our fair share'. Some nations are going to have to do more than others in order to prevent further dangerous climate change. In part, the duty of those who act is reinforced by the fact that other nations are not acting – the fact that some nations are not taking action makes the problem all the more urgent and dire, and reinforces the moral obligation of those nations that can and will act.

Moreover, if we focus on just the nations in the Baker's Dozen, it is apparent that ignoring the rest of the world raises less of a concern than it might seem to. It is unclear exactly what fairness dictates in mitigating climate change (decades of climate debate speak to this), but the rest of the world's historical and current emissions are so small compared to the Baker's Dozen that leaving them out is not all that far from 'fair'. Of course, over time, the countries included in the sub-group would have to be adapted as new large emitters emerge, but nothing within our approach prohibits this and we see room for multiple coalitions forming à la the Baker's Dozen.

> Climate change is such a huge issue that it requires strong, concerted, consistent and enduring action by governments.
> / Peter Garrett /

Conclusion

While a side agreement would require significant and urgent reductions in emissions from its signers, we conclude that it is possible to avoid further dangerous climate change if a sub-group of thirteen nations – minimally the US, EU-27, Japan, China, India, Russia, Canada, South Korea, South Africa, Mexico, Indonesia, Australia, and Brazil – take immediate action. This action would involve deep and rapid cuts in emissions in the short-term and large-scale carbon sequestration in the medium-term. A side deal circumvents the collective action problem plaguing global climate negotiations and, as both game theory and political science teach us, may enable more rapid and aggressive agreements.

The normative case for the approach is built on the principle that every nation has a duty to act, but we are in such a dire situation that pursuing second-best solutions is appropriate. Key moral concerns that have dominated climate discussions should come secondary to achieving action; but we show that some can be integrated with an eventual side deal policy and can remain the aim of long-term climate change policy. Moral concerns, and particularly concerns about justice, can "muddy the picture and threaten to interfere with efforts to negotiate an effective climate change regime in the future,"[33] but they need not conflict with pragmatic approaches. We believe that finding ways in which pragmatic concerns and moral considerations align can strengthen the case for effective climate policies.

We urge the current global climate change negotiating forum – culminating in Copenhagen in December 2009 – to be a venue which facilitates side deals. We fear a sole focus of achieving a global consensus on binding targets will not achieve the level and speed of reductions needed, nor result in long-term buy-in by key nations. While imperfect, we believe our approach could be a way to break out of the collective action stalemate and prevent widespread, irreversible impacts.

Notes:

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2. Stanford Institute for Economic Policy Research.

3. Department of Philosophy, University of Washington, Seattle.

4. Intergovernmental Panel on Climate Change and Woods Institute for the Environment, Stanford University.

5. A thorough review of the literature is provided in Aldy and Stavins 2007.

6. Victor 2006.

7. Barrett 2001.

8. Sands 2003.

9. Barrett 2006.

10. Hoel 1989.

11. We consider the Bush-era side deal negotiations as an intentional derailment from effective climate policy negotiation, rather than an example of the type of coalition building we are discussing.

12. Solomon et al. 2007; Rogelj et al. 2009.

13. Smith et al. 2009.
14. Smith et al. 2009. Note the baseline in Smith is 1990; we do not adjust for the ~0.15 degree warming between 1990-2000 because it is swamped by the range's uncertainty.
15. Parry et al. 2007.
16. The West Antarctic Ice Sheet is 11,000 years old, while the Greenland Ice Sheet is over 110,000 years old.
17. See Solomon et al. 2007 / Hansen et al. 2008 for discussion of the uncertainty in this estimate.
18. Solomon et al. 2007 / Meinshausen el al. 2006 / Hansen et al. 2008
19. Luers et al. 2007; Parry et al. 2007; Meinshausen et al. 2006.
20. See Solomon et al. 2009.
21. Luers et al. 2007. We derive this budget by converting Luers' cumulative emissions budget of 1,690 Gt CO2eq to ~460 Gt C, and then adjust the resulting cap to ~290 Gt C to reflect the portion of the radiative flux coming from carbon dioxide (about 63 percent): Raupach et al. 2007.
22. Note in this paper, we focus on carbon dioxide emissions from fossil fuel consumption to make the analysis clearer.
23. The EU-27 are considered one 'nation' in this paper.
24. Meinshausen et al. 2006; Den Elzen/ Meinshausen 2006; Pachauri/Reisinger 2007.
25. World Resources Institute 2007.
26. World Bank 2009.
27. Raupach et al. 2007.
28. Metz et al. 2007; Metz/Van Vuuren 2006; Metz et al. 2005; Electric Power Research Institute 2007.
29. Hansen et al. 2008; Metz/Van Vuuren 2006.
30. Rai et al. 2009.
31. Posner/Vermeule 2003; Sunstein 2009.
32. Pachauri/Reisinger 2007; Stern 2007.
33. Posner/Sunstein 2007: 20.

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